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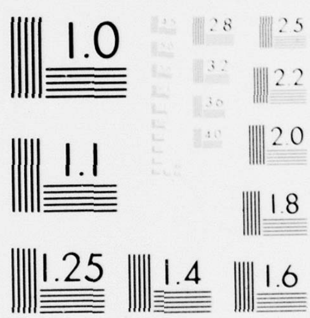

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STORAGE RELIABILITY

OF

MISSILE MATERIEL PROGRAM

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

ACCELEROMETER ANALYSIS

LC-78-EM2

FEBRUARY 1978

Redstone Arsenal, Alabama 35809

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This report documents findings on the non-operating reliability of accelerometers. A total of 449 million part hours were examined. The best storage failure rate for accelerometers is 29.7 fit (failures per billion hours) with one sided 90% confidence level of 59 fit. Construction principles are described and desirable storage conditions indicated. This information is part of a research program being conducted by the U. S. Army Missile

20. Abstract (cont'd)

R&D Command, Redstone Arsenal, Alabama. The objective of this program is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. This report updates and replaces report LC-76-EM2 dated February 1976.

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STORAGE RELIABILITY

OF

MISSILE MATERIEL PROGRAM

ACCELEROMETER ANALYSIS

LC-78-EM2 FEBRUARY 1978

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HUNTSVILLE, ALABAMA

ABSTRACT

This report documents findings on the non-operating reliability of accelerometers. Long term non-operating data has been analyzed and reliability predictions have been developed for accelerometers.

This report is a result of a program whose objective is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. The analysis results will be used by U. S. Army personnel and contractors in evaluating current missile programs and in the design of future missile systems.

The storage reliability research program consists of a country wide data survey and collection effort, accelerated testing, special test programs and development of a non-operating reliability data bank at the U. S. Army Missile Research and Development Command, Redstone Arsenal, Alabama. The Army plans a continuing effort to maintain the data bank and analysis reports.

This report is one of several issued on electromechanical devices and other missile materiel. For more information, contact:

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SECTION 1

INTRODUCTION

Materiel in the Army inventory must be designed, manufactured and packaged to withstand long periods of storage and "launch ready" non-activated or dormant time. In addition to the stress of temperature soaks and aging, they must often endure the abuse of frequent transportation and handling and the climatic extremes of the forward area battle field environment. These requirements generate the need for special design, manufacturing and packaging product assurance data and procedures. The U. S. Army Missile R&D Command has initiated a research program to provide the needed data and procedures.

This report updates report LC-76-EM2, dated May 1976 and covers findings from the research program on accelerometers. The program approach on these devices has included literature and user surveys, data bank analyses, data collection from various military systems and special testing programs.

SECTION 2

SUMMARY

Non-operating reliability data has been obtained to date from five sources and six missile programs for a total of 448.5 million non-operating hours. The best observed failure rate for accelerometers is 29.7 fits (failures per billion hours) with 90% confidence that the true failure rate lies below 59 fits. Observed failure rates in the five programs range up to 1923 fits. The non-operating to operating failure rate ratio is 1768, where the operating rate is for the ground environment.

SECTION 3

ELEMENTARY PRINCIPLES OF ACCELEROMETERS

An accelerometer is designed using the Newtonian relation $F = ma$. A known proof mass, m, is constrained to follow the motion of the case of the device by means of a constraining force, F, which is measured, whence the acceleration, a, can be calculated. As a matter of convenience, the measurement is often made only along a single axis. The constraining force can be provided in a number of ways, some of which are:

a) by a simple spring. The relative displacement is the measure of the force. This configuration is not much used, because only a low accuracy is possible.

b) by an unsaturated electromagnet. The current is proportional to the force. In some designs, the current is a pulse of fixed magnitude and duration, a count of the number of pulses is then proportional to the velocity acquired.

c) by a gyroscope. The precession rate is proportional to the acceleration. This configuration is usually used with a servo to null the precession angle.

d) by a set of taut wires. The tension in each wire is determined by using a pickoff and exciter to determine its resonant frequency.

In inertial applications, the integral of the acceleration (velocity gained) is usually wanted. If this is done within the accelerometer, it is termed an integrating accelerometer or a velocity meter.

SECTION 4

DATA ANALYSIS

4.1 Data Description

Data was received from 5 sources and 6 missile programs representing 448.5 million non-operating hours with 196 failures reported. Analysis of the data indicated that the data from two missile programs could not be used in deriving a non-operating failure rate.

All of the data is shown in Table 4-1. Missile M data listed accelerometer removals, however, no analysis was performed to determine the actual number of failed units. Missile T data recorded assembly failures. The assemblies consisted of two accelerometers, a roll free gyro and a roll corrector. Data was unavailable to determine which assembly failures were a result of accelerometer failures.

The remaining data includes 137.8 million non-operating hours with 10 failures giving an average non-operating failure rate of 73 fits (failures per billion hours). The failure rates for sources indicating failures range from 24 fits to 1923 fits.

Each data source is discussed below.

4.1.1 Source A Data

Source A represents a reliability study performed under contract to RADC in 1974. This source identified the type and quality grades for the devices, however, it provided no information regarding storage conditions or individual programs.

4.1.2 Source B Data

The storage data under Source B actually represents standby data in an orbiting satellite environment. No failures were indicated in 110 thousand accelerometer standby hours.

4.1.3 Source C Data

Source C represents a reliability study performed under contract to RADC in 1968. It included 2506 devices stored for an average of 5 months. The devices were missile hardware. No failures were reported.

TABLE 4-1. ACCELEROMETER NON-OPERATING DATA

SOURCE	NO. OF DEVICES	MILLION PART STORAGE HRS.	FAILURES	FAILURE RATE IN FITS	COMMENT
A	-	3.12	6	1923.	Pendulum
A	-	0.25	0	<4000.	Angular
A	-	0.46	0	<2174.	Linear
B	18	0.11	0	<9091.	
C	2506	9.3	0	<108.	
M	115	4.44	0	<225.	2df Pendulum
P	34	1.30	1	769.	
MISSILE					
E-1	1748	25.521	0	<39.	
G	39	1.118	1	894.	
H	1071	17.015	1	59.	Linear
H	2142	34.029	0	<29.	Angular
I	4140	41.18	1	24.	
SUB TOTAL		137.843	10	73.	
OTHER DATA					
MISSILE M	-	30.6	76	2484.	76 removals
MISSILE T	6000	310.	105	349.	Assy. Failures
TOTAL		448.533	196	437.	

4.1.4 Source M Data

Source M represents spacecraft accelerometers which were part of systems stored in a controlled environment. The systems were tested once per year with no accelerometer failures reported. Average age of accelerometers at last test were 5.3 years.

4.1.5 Source P Data

Source P data represents a special aging and surveillance program. Devices are stored in a controlled environment. One device failed in a storage test at age three months. No failure analysis was available, however, the device was listed as not repairable. Two other devices failed tests, however, on retest, both devices performed satisfactorily. At last test, devices ranged in age from 1 month to 74 months. Average age was 52 months. No aging trends are evident from the tests.

4.1.6 Missile E-1 Data

Missile E-1 data consists of 874 missiles stored for 20 months. The missiles were stored in containers exposed to external environmental conditions in the northeast U. S. They were also transported once from coast to coast. No accelerometer failures were reported when tested at 20 months.

4.1.7 Missile G Data

Missile G data consists of 39 missiles stored for periods from 28 months to 56 months for an average storage period of 39 months. The missiles in storage containers experienced the following environments: 12 missiles stored outside in the southeast desert; 12 missiles stored outside in the northeast U. S.; 12 missiles stored on the Gulf Coast; and 23 missiles stored in bunkers in the southeast U. S. One accelerometer failure has been reported at age 47 months. Failure analysis indicated a failed thermistor (possibly due to electrical overload).

4.1.8 Missile H Data

Missile H data represents field data from a recent army missile program fielded in the 1970's. The major item in which the devices were assembled was subjected to operating times at high and low temperatures, shock and vibration. The missiles were transported overseas and stored for various lengths of time. No tests were run until the missiles were removed from storage and returned to the states. Storage durations varied from 6 months to 6 years with an average time of 1.8 years.

Storage environments included cannister time in a controlled environment, cannister time subject to outside elements and missile time on pallets and on launchers. A number of samples were also run through road tests under field conditions. One linear accelerometer failure was recorded at age 26 months. Failure analysis indicated a poor bond on accelerometers silicon beam (sensing element).

4.1.9 Missile I Data

Missile I data consists of 2,070 missiles stored for periods from 1 month to 40 months for an average storage period of 14 months. Approximately 80 percent of the missiles were stored in U. S. depots while the remainder were stored at various bases around the country. One accelerometer failure was recorded at age 14 months. No failure analysis was available.

4.1.10 Missile M Data

Missile M data represents a surface-to-surface missile: Data was available on approximately 13 years of depot repair history. With 30.6 million hours exposure, there were 76 accelerometer removals,however it was not possible to determine the number that were actually failed units. Based on gyro records for the same system, the failed units would account for only .5 to .33 of the removals.

4.1.11 Missile T Data

Missile T data represents a surface-to-air missile. Data on a 3,000 missile inventory for an average of 71 months is included. At test, missile ages ranged from 6 months to 8 years. The missiles, built in the 1954 time frame, contained an assembly with two accelerometers, a roll free gyro, and a roll connector. Data was unavailable to determine which assembly failures were a result of accelerometer failures.

4.2 Data Evaluation

Pooling data from the useable sources results in 10 failures in 137.843 million storage hours giving a failure rate of 73 fits. The failure rates for those sources showing

failures range from 24 to 1923 fits. A test of significance (described in Appendix A) was performed to test whether a single failure rate could describe all the data sets. The test indicated that there was a significant difference with one data set having a significantly higher failure rate. This data set was removed and the remaining data sets retested indicating no significant differences.

The pooled data is shown in Table 4-2 with 134.723 million storage hours and 4 failures. The non-operating failure rate based on this data is 29.7 fits with a 90% confidence that the failure rate is less than 59 fits. The average age of the pooled data sets is 16 months with the oldest units being 74 months old.

No factors can be identified to account for the larger reported failure rate for pendulum accelerometers in Source A. The sources showing the lowest failure rates (Missiles H and I) are also the newest systems in the data sets. Both systems are early 1970 technology.

TABLE 4-2. POOLED DATA SETS

SOURCE	NO. OF DEVICES	MILLION PART STORAGE HRS.	FAILURES	FAILURE RATE IN FITS
A	-	0.25	0	<4000.
A	-	0.46	0	<2174.
B	18	0.11	0	<9091.
C	2506	9.3	0	<108.
M	115	4.44	0	<225.
P	34	1.30	1	769.
MISSILE				
E-1	1748	25.521	0	<39.
G	39	1.118	1	894.
H	1071	17.015	1	59.
H	2142	34.029	0	<29.
I	4140	41.18	1	24.
TOTALS		134.723	4	29.7

4.3 Operational/Non-Operational Reliability Comparison

Operational failure rate data for accelerometers was extracted from report RADC-TR-74-268, Revision of RADC Nonelectronic Reliability Notebook, D. F. Cottrell, et al, Martin Marietta Aerospace, dated October, 1974. This data is shown in Table 4-3 and compared with the non-operating failure rate prediction. Comparing the common environment (ground) indicates a non-operating to operating ratio of 1:1768.

TABLE 4-3. OPERATIONAL/NON-OPERATIONAL RELIABILITY COMPARISON

ENVIRONMENT	PART HOURS (10^6)	NO. OF FAILURES	FAILURE RATE IN FITS	$\lambda_{op}/\lambda_{no}$
Non-Operating				
Ground, Fixed	134.723	4	29.7	-
Operating				
Satellite	.112	0	<8179.	275.
Ground	9.234	485	52523.	1768.
Ground, Mobile	.037	0	<24757.	834.
Airborne	11.07	2619	236607.	7967.

4.4 Acceptance Tests

Missile H reports that the following tests are run on every accelerometer.

A. Thermal Shock, with 50 cycles at 1G in one plane, at
-25°F for 1/2 hour,
+77°F for 5 minutes max.,
+165°F for 1/2 hours, and
+77°F for 5 minutes max.

B. Major item screening (incorporating the accelerometer)
(1) Run time: 32 hours total, for 16 hours of which item is subjected to temperature cycle of 61°C for 1 hour on and 1 hour off.
(2) Shock: 50g -5 millisecond half sine wave, 1 plane
(3) Random Vibration: 3 planes for 6 minutes each, at approximately 0.02 g^2/hz from 20 to 2000 hz

4.5 Failure Modes & Mechanisms

Reference 8 (p. 56) contains a rough classification of accelerometer failures. Most of the failures reported there reflect a contamination problem. The two failure causes reported in the non-operating data appear to be random type occurrences. No aging trends have been indicated in any of the data.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Accelerometers do not appear to present any significant reliability problems in storage. The random failures that have been reported appear to be a result of slight weaknesses in the parts in manufacture or in the testing process. No aging trends have been identified for devices up to 74 months in age.

The non-operating failure rate developed in Section 4 of 27.9 fits is recommended as being representative of the current technology.

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APPENDIX A

TEST OF SIGNIFICANCE OF DIFFERENCES IN FAILURE RATES (MORE THAN TWO POPULATIONS)

The storage reliability data is obtained from numerous sources. A detailed qualitative analysis is performed on the data to classify devices, environments, uses, quality levels, failures modes & mechanisms, and so on. Once the data sets are grouped according to these analyses, it is still not certain whether grouped sets of failure data are in truth from the same statistical population. It is possible that the failure rate characteristics of identical devices from the same manufacturers, with the same application, use environment, and so on, are not from the same population in terms of reliability -- possibly due to some problem on a production line for a certain lot or other factor.

Therefore a statistical test is performed to determine if the different data sets could be from the same statistical population.

The technique used is for more than two data sets and is taken from "Statistical Methods for Research Workers," R. A. Fisher, 13th edition, Hufner, 1963, pages 99-101.

The techniques assumes that the underlying failure distributions each have the same constant failure rate (λ). Therefore, the probability of a number of failures for each population can be represented by the Poisson distribution.

A single failure rate is calculated based on the pooled data sets being tested.

$$\lambda = \frac{\sum_{i=1}^{N} f_i}{\sum_{i=1}^{N} T_i}$$

where λ = Mean failure rate for all data sets

f_i = the number of failures in data set i

T_i = the total storage hours in data set i

n = the number of data sets being tested

The expected number of failures and the difference between the expected number of failures and actual failures is calculated for each data set based on the pooled data:

$$M_i = \lambda T_i$$

$$d_i = |f_i - m_i|$$

where

M_i = expected number of failures for data set: (based on the pooled data sets)

d_i = absolute value of the differences between the expected number of failures and the actual failures for data set i.

Next, lower and upper limits are calculated for the Poisson distribution:

$$U_i = [M_i + d_i] \text{ (if } U_i = f_i\text{, set } U_i = f_i - 1)$$

$$L_i = \langle M_i - d_i \rangle \text{ (if } L_i = f_i\text{, set } L_i = f_i + 1)$$

$$\text{(if } L_i < 0\text{, set } L_i = 0)$$

U_i = upper limit for data set i

L_i = lower limit for data set i

[ ] = rounded down to integer value

< > = rounded up to integer value

The probability that f_i failures would occur in data set i given the population failure rate is λ, is expressed by the Poisson distribution:

$$P_i = 1 - \sum_{j=L_i}^{U_i} P_{ij}$$

$$= 1 - \sum_{j=L_i}^{U_i} e^{-M_i} \frac{M_i^{\,j}}{j!}$$

The individual probabilities, P_i, are the significance probabilities for the individual distributions. It is required to test whether the ensemble of P_i taken together represents an improbable configuration under the null hypothesis which is that the underlying distributions have the same constant failure rate (λ).

The test is done as follows:

$$C_i = -2 \ln P_i$$

$$C = \sum_{i=1}^{n} C_i$$

Find Cr for $\alpha = .05$ (5% level of significance) and 2n degrees of freedom from the tables of chi square.

If C>Cr reject the null hypothesis (that all of the populations have the same failure rate.)

If the null hypothesis is not rejected, the data sets can be pooled and the common failure rate λ used.

If the null hypothesis is rejected, engineering and statistical analysis is required to remove data sets from the pooled data until the null hypothesis is not rejected.

EXAMPLE 1:

DATA SET	T_i	F_i	M_i	d_i	U_i	L_i	P_i	C_i
1	587.4	19	12.9	6.1	18	7	.0936	4.74
2	144.1	0	3.2	3.2	3	1	.0849	4.93
3	65.6	1	1.4	.4	2	2	1.000	0
4	95.8	1	2.1	1.1	3	2	.5406	1.23
5	128.	3	2.8	.2	3	3	1.000	0
6	281.	15	6.2	8.8	14	0	.0018	12.60
7	78.6	2	1.7	.3	1	1	1.000	0
8	484.8	0	10.7	10.7	21	1	.0016	12.93
	1865.6	41					ΣC_i =	36.43

pooled - λ = 21.98 fits

C = 36.43

2n degrees of freedom = 16

(from chi-square dist. at α = .05) Cr = 26.30

Since C>Cr ---- the null hypothesis, that all of the populations have the same failure rate, is rejected.

EXAMPLE 2:

DATA SET	T_i	f_i	M_i	d_i	U_i	L_i	P_i	C_i
1	587.4	19	19.5	.5	20	20	1.0	0
2	65.6	1	2.2	1.2	3	2	.536	1.2
3	95.8	1	3.2	2.2	5	2	.277	2.57
4	128.	3	4.2	1.2	5	4	.641	.89
5	281.	15	9.3	5.7	14	4	.070	5.33
6	78.6	2	2.6	.6	3	3	1.02	.0
	1236.4	41						9.99

Pooled λ = 33.16 fits

C = 9.99

2n degrees of freedom = 12

Cr = 21.03

C<Cr - accept null hypothesis --

All data sets have the same failure rate (λ = 33.16 fits).